December 31, 1966

Dr. Maurice Dubin
Code SG
NASA Headquarters
Washington, D. C.

Dear Dr. Dubin:

This is the eighth quarterly status report on NASA Contract NASr-65(11)/14-003-911 (IITRI Project W6120). This report describes the work performed under this contract during the period 1 October 1966 through 31 December 1966.

1. Work Performed

Further examinations of ionospheric and airglow data were undertaken during this period which have yielded preliminary results which look extremely promising. Due to the difficulty of corresponding with Dr. Peterson at his new location in Jicamarca, Peru, progress on the preparation of these results for publication has been delayed and the paper will not be completed during this period. Enough funds remain however to permit the completion of this phase of the work early in 1967. We feel that these preliminary results and remaining unanalyzed data contain significant information and warrant further study. Consequently, a proposal will be submitted requesting additional support for a continuing effort through 1967. Some of the more interesting developments are described briefly below*:

a) Time Distribution of Mid-Night 6300 $\overset{o}{A}$ Enhancements as a Function of Latitude

$_o$ The time of maximum intensity and the duration of the 6300 $\overset{o}{A}$ enhancements observed during the 1965 Mobile Launch Expedition are shown in Figure 1 as a function of latitude.

*Figures are included in Dr. Dubins copy only.

Because of the large fluctuations in the 6300 Å zenith
intensity observed on many nights, the selection of enhance-
ments and determination of their duration requires a fair
amount of subjective judgment. A sufficient number of
unambiguous enhancements exist however, to confirm the
general behavior with latitude.

At equatorial latitudes the maximum generally occurs
within one hour of local midnight. Poleward of this region
the enhancements occur before and/or after local midnight
by as much as three hours. For the latitude range covered
by these airglow observations, the departure of the time of
maximum intensity from local midnight appears to increase
with distance from the equator. The equatorial midnight
enhancement breaks up into distinct early and late night
enhancements which appear to continually separate as we
proceed poleward until we reach mid-latitudes where they
become the post-twilight and pre-dawn enhancements. A
symmetry in the N-S displacement of the 6300 Å enhancements
with respect to local midnight is evident in Figure 1.
The center of symmetry is located near 3°S geographic
latitude although the clustering of 6300 Å maxima near local
midnight occurs farther south; the equatorial spread covers
nearly 20° of latitude.

The latitude range coverage in Figure 1 is limited,
due largely to poor optical observing conditions below
25°S latitude. Since Barbier's semi-empirical formula
accurately represents the 6300 Å intensity variations in
equatorial and temperature latitudes (as described later)
we can hope to extend the latitude range of this study by
considering minima in h'F or maxima f_oF_2. Because the
virtual height data are more complete, we will restrict
ourselves here to the latitude behavior of h'F minima as
illustrated in Figure 2. The temporal distribution and
duration of h'F minima reproduce the behavior of the 6300 Å
enhancements in equatorial regions. The displacement of the
time of enhancement from local midnight continues to increase
as higher latitudes are approached. The blending of the
minima with the low heights at sunset and sunrise at mid-
latitudes corresponds to the blending of the 6300 Å enhance-
ments into the post-twilight and pre-dawn effects. A good
fit to the departure of enhancement time from local midnight
is represented by NW-SE and NE-SW arcs shifting from the
midnight meridian by 60° longitude/40° latitude.

b) Latitudinal and Seasonal Variations in the
   Diurnal 6300 A Intensity

This description involves a combination of the anti-solar point correlation (published) and the breakup of the midnight enhancement into two discrete features (as described above).

An isophote map was constructed from portions of the 1959/60 airglow data from the Japanese ship SOYA showing high levels near 20°N latitude, especially near midnight. This is close to the anti-solar latitude for the dates considered. The similarities in the diurnal behavior, in local time, for these and most reported data argue strongly against a N-S arc motion and favor a fixed Earth-Sun excitation pattern with the Earth's rotation effecting the variations. The excitation pattern, of course, must shift with season. Assuming that such a pattern exists, we let the h'F minima distribution describe its gross features. The pattern then includes a SW-NE band and a SE-NW band which cross at local midnight at the latitude of the anti-solar point. The inclination of the arcs is taken from the h'F data (see Figure 2). The excitation patterns are illustrated in Figures 3 for the first day of each month. The width of these arcs are taken as 2 hours (30 degrees) to correspond to the duration of typical enhancements. These arcs are terminated at times of astronomical twilight which are also shown in the figures.

Assuming arbitrary intensity levels to each region of the sky, we can construct diurnal plots for several latitudes for each month. The intensity values assumed were

$$
\begin{aligned}
\text{Night sky} &= 0 \\
\text{Excitation pattern} &= 1 \\
\text{Crossover pattern} &= 2 \\
\text{Twilight and day} &= \text{infinity}
\end{aligned}
$$

The resulting plots are shown in Figures 4. These plots illustrate quiet behavior, post-twilight and pre-dawn enhancements, broad and sharp midnight enhancements, double peaks, etc. More interesting is the way in which the general 6300 behavior for numerous sites is predicted by this hypothesis. To quote a few examples:

Carman, E. H. and B. C. Gibson-Wilde, "Seasonal Variation of the OI 6300 Å Airglow at Townsville from Isophote Sky Maps," J.G.R. 69, 487 (1964).

They report a marked increase in middle night levels during the period July-November at Townsville (19.25°S). Figures 3 show the crossover region at this latitude from May-September. The 2-month deviation may be "explained" by including the magnetic field geometry. For instance, the magnetic equator at the longitude of Townsville is near 8°N. Shifting the pattern to correspond to some position between the anti-solar latitude and the equator would delay the appearance of the crossover region at Townsville. In fact, shifting it halfway between the two would cause the crossover to appear in July. Until some physical basis for such a pattern is found, this kind of shift will be difficult to justify.

Bellew, W. and S. Silverman, "General Behavior of 6300 A OI at Sacramento Peak, New Mexico," Planet. Space Sci. 14, 407 (1966).

In their Figure 1 they give four examples of red line behavior at Sacramento Peak (30°43'N). For March 18/19 they show a strong post-twilight effect as predicted in our April 1 plot for 30°N. For November 20/21 they show a midnight enhancement as predicted for December 1. For February 27/28 strong post-twilight and midnight effects exist (some disagreement) and for April 16/17 a strong post-twilight effect as predicted. For February 27/28 we predict a post-twilight effect by including the magnetic geometry as for Townsville.

Silverman, S. and M. Casaverde, "Behavior of the 6300 OI Line at Huancayo," J.G.R. 66, 323 (1961).

The predications satisfy seasonal trends between Tamanrasset, Lwiro and Huancayo. As examples of the Huancayo midnight enhancements he shows data from June 11-July 20, presumably because the effects are strongest then. This is as predicted by the excitation pattern.

Davis, T. N. and L. L. Smith, "Latitudinal and Seasonal Variations in the Night Airglow," J.G.R. 70, 1127 (1965).

They claim observation of post-twilight and pre-dawn effects at all latitudes with midnight enhancements only on June 2 and June 6. They departed New York in March (post-twilight predicted) and moved north. They departed New York again May 24 and arrived in Valparaiso on June 27. (Behavior again is predicted in the north.) Midnight effects are predicted in the south and were observed on the 2 nights listed. From July to November they cruised south of Valparaiso (again post-twilight or early night effects predicted).

Huruhata, M., "Airglow Intensity Observed on the SOYA Japanese Expedition Ship to the Antarctic 1956-1962," JARE Scientific Report, Series A, No. 2 (October 1963).

Spot checks with several nights showed excellent agreement although some contradictions exist.

Smith, L. L. and R. W. Owen, "Seasonal Variation of Nightglow NaI 5890-96A, OI 5577 Å and OI 6300 Å in the Tropics," NBS Tech. Note 329 (January 10, 1966).

The agreement between tabulated Haleakala data and these predictions is poor.

The extension of the excitation pattern poleward of mid-latitudes cannot be deduced from these data, however it is interesting to speculate that the arcs fold into the auroral zone.

Further examination of other ionospheric data (V. Peterson) suggests that this pattern is absent during solar maximum while being strongly hinted at in solar minimum data.

c) <u>Reproduction of the 6300 Å Excitation Pattern from Ionospheric Data</u>

Subsequent to the preparation of the 6300 Å isophote map for the launch expedition observations, V. Peterson prepared an isoheight plot for values of $h'F$ and an isofreq plot for values of f_oF_2. These three plots have been redrawn using average values for each element within a 10° latitude by 15° (1 hour) longitude grid. These are shown in Figures 5 6 and 7. Note that neither the isoheight nor isofreq plots resemble the isophote pattern. Barbier's formula has been applied to the data in these figures in several ways and isophote plots have been prepared from the calculations.

In Figure 8 we applied Barbier's formula to data in each latitude range separately and plotted the results for H = 40 km. Correlation coefficients ranged from 0.717 to 0.990 with an average value of 0.850.

In Figure 9 the same procedure was used but the scale height giving the best correlation at each latitude was chosen. Scale heights ranged from 26 km to 60 km with an average value of 46 km. Correlation coefficients ranged from 0.722 to 0.992 with an average value of 0.865.

In Figure 10 all data was treated simultaneously. The optimum correlation coefficient was 0.722 for H = 48 km.

In all three cases the similarities of the gross features in the calculated and observed isophote patterns is striking. It is evident that neither the effective height nor the critical frequency controls the shape of the excitation pattern.
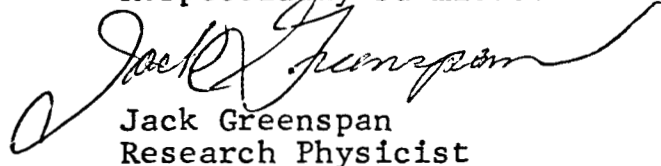
2. Future Work

The results described above along with examples of Barbier correlations for individual nights and airglow features will form the essentials of a paper in preparation. Refinements of these results and a number of other analysis tasks will be outlined and will be submitted to NASA Headquarters for 1967 funding.
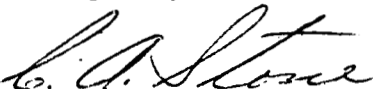
3. Cost Data

Total reported expenditures as of November 31, 1966 were $33,669, with committments of $285.00 leaving an uncommitted balance of $2,643.

Respectfully submitted

Jack Greenspan
Research Physicist

APPROVED:

C. A. Stone, Director
Astro Sciences Center